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Perspective Article

Scientists' warning on fossil fuels

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Abstract

The evidence is clear that fossil fuels—and the fossil fuel industry and its enablers—are driving a multitude of interlinked crises that jeopardize the breadth and stability of life on Earth. Every stage of the fossil fuel life cycle—extraction, processing, transport, and combustion or conversion to petrochemical products—emits planet-heating greenhouse gases and health-harming pollutants, in addition to causing widespread environmental degradation. We review the vast scientific evidence showing that fossil fuels and the fossil fuel industry are the root cause of the climate crisis, harm public health, worsen environmental injustice, accelerate biodiversity extinction, and fuel the petrochemical pollution crisis. Fossil fuels are responsible for millions of premature deaths, trillions of dollars in damages, and the escalating disruption of ecosystems, threatening people, wildlife, and a livable future. The fossil fuel industry has obscured and concealed this evidence through a decades-long, multi-billion-dollar disinformation campaign aimed at blocking action to phase out fossil fuels. We focus on the United States as the world's largest oil and gas producer and dominant contributor to these fossil fuel crises. We present the science-and-justice-based solutions that already exist for governments and civil society to restrict the influence of the fossil fuel industry, stop fossil fuel expansion, phase out fossil fuel production and use, and make a rapid, just transition to clean, renewable energy and materials across the economy, while holding the fossil fuel industry accountable for its deception and damages. The necessary transition away from fossil fuels will provide innumerable societal and planetary benefits and forge a path forward to sustaining life on Earth.

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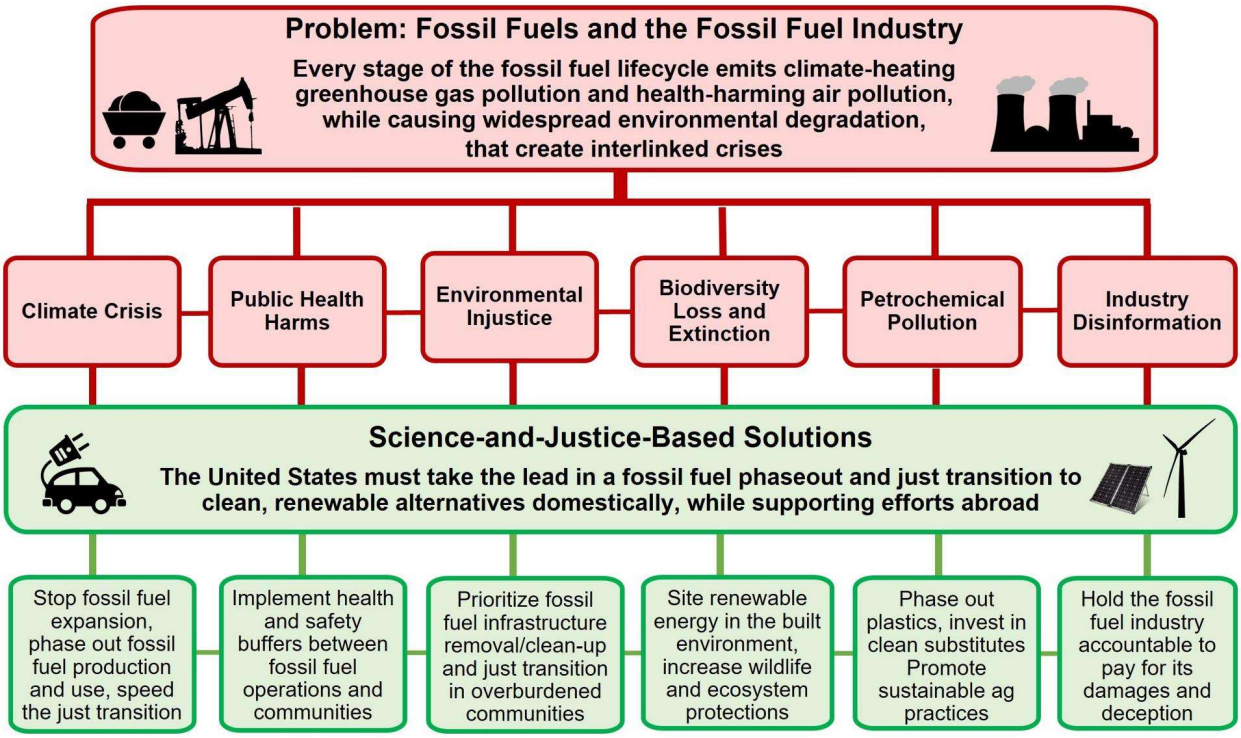
Graphical Abstract



Keywords: Fossil Fuels; Climate Change; Public Health; Environmental Justice; Biodiversity; Petrochemicals; Disinformation; Phaseout

Introduction

United Nations Secretary-General António Guterres warned in 2023 that fossil fuels are "incompatible with human survival" and that governments must take urgent action to phase them out and boost the renewable energy transition to avoid catastrophe [1]. This stark warning was based on the vast foundation of scientific evidence, built over decades, establishing the widespread and devastating harms of fossil fuels and the urgent need for a fossil fuel phaseout, including a just transition to clean alternatives to protect people and the planet. In the 1950s and '60s, scientists were alerting the public, and the fossil fuel industry itself, that fossil fuel use causes anthropogenic climate change and could lead to disastrous damages if unchecked [2, 3]. Since the 1980s, thousands of published studies have been synthesized into massive reports by the Intergovernmental Panel on Climate Change (IPCC) and other research bodies, confirming the scientific consensus on climate change and documenting the escalating harms of the fossil-fueled climate crisis [4, 5]. Likewise, decades of research and documentation by scientists, frontline communities, and advocates have demonstrated other pervasive harms caused by fossil fuels: illness and deaths, environmental injustice, harms to wildlife and ecosystems, and the escalating problems from plastics and other petrochemical pollution.

As the evidence on the dangers of fossil fuels has grown, an array of solutions to replace fossil fuels has emerged. Clean and cost-effective renewable energy and alternative material sources have been developed across the economy, making electrification possible in most sectors and collectively facilitating a just transition away from fossil fuels [6–9]. Renewable power from solar photovoltaic (PV) and onshore wind is much less expensive than fossil-fueled electricity [10]. Battery storage costs are rapidly declining and renewable power capacity additions and clean-energy job creation continue to set records [10–12]. In the USA the transition to a clean, renewable energy system powered primarily by solar and wind energy, paired with energy efficiency and storage, has been shown to be feasible, cost-effective, and reliable [13–21]. A clean energy transition would lead to estimated trillions in health and environmental benefits, while boosting job creation and local economies across the USA [9, 22].

Despite the compelling evidence and availability of clean, renewable energy, government action to limit fossil fuels has been slow and inadequate. Fossil fuel companies still receive massive government subsidies [23], governments are still expanding fossil fuel production and infrastructure [24], and global fossil fuel emissions continue to rise [25]. For almost three decades, international negotiating meetings under the United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1992 to "prevent dangerous human interference with the climate system," failed to result in any agreement on the need to reduce fossil fuels.

However, a powerful combination of moral, economic, scientific, and political pressure has been mounting to phase out fossil fuels and speed a just transition to clean alternatives. Calls for an equitable phaseout require countries to reduce the production and use of fossil fuels over time to zero, based on several core principles. Countries and sub-national jurisdictions must pair "supply side" policies to decrease fossil fuel production with "demand side" policies to decrease fossil fuel consumption to

effectively reduce emissions and allow for full fossil fuel phaseout [26–31]. Policies that reduce domestic fossil fuel demand—while simultaneously approving long-lifespan fossil fuel infrastructure, extraction, and export projects—perpetuate and further lock in fossil fuels and their harms [32, 33]. Therefore, calls for fossil fuel phaseout emphasize ending new fossil fuel production and infrastructure. Fossil fuel phaseout must also avoid "false solutions" that perpetuate—and all too often subsidize—fossil fuel extraction and infrastructure, such as carbon capture and storage (CCS) and hydrogen made from fossil fuels. And fossil fuel phaseout must be based on equity. Wealthy countries most responsible for fossil fuel emissions and with most capacity to act bear the greatest responsibility for ambitious climate action, including significant climate finance and support to poorer countries [34–37].

Fossil fuel phaseout in alignment with "just transition" principles entails replacing fossil fuels with affordable, accessible, clean, renewable energy that produces virtually no lifecycle greenhouse gas emissions or pollution, in a fair and equitable way. Though there is no single definition, just transition is centered on helping disadvantaged communities and workers in the transition while avoiding reproducing the socio-economic and environmental injustices intrinsic to the fossil fuel energy system [38–40]. The transition must come with safeguards to minimize harms to communities, workers, and the environment during the extraction of critical minerals necessary for renewable expansion—including optimizing extraction methods, minimizing critical mineral demand through recycling and repurposing, and consulting with potentially impacted communities [41]. Illustrating these principles, Climate Action Network International, comprised of more than 1900 civil society organizations around the world, has called for governments to lead a "fair, fast, full, and funded phase out of fossil fuels in all sectors and replace those with clean solutions of 100% renewables for energy and industrial processes in a just and equitable way by 2050 latest while historically and presently large and rich polluters have to move earlier" [42].

Growing momentum from climate and environmental justice movements has been a key driver of the global call for fossil fuel phaseout and just transition. The effort has been led by frontline communities and youth, pushing governments, decision-makers, and the public to take action to phase out fossil fuels. In September 2023, a global mobilization calling for an end to fossil fuels saw 600 000 people join more than 700 actions in 65 countries, culminating in the 75 000-person *March to End Fossil Fuels* in New York City [43]. Another key driver has been ground-breaking investigative journalism and scholarship in recent years that has uncovered the multi-decade, multi-billion-dollar disinformation campaign waged by the fossil industry and its allies to downplay or deny the harms of its products and delay action to phase out fossil fuels [2, 44]. Exposing this disinformation has been critical for helping scientists, policymakers, and the public understand why action to transition away from fossil fuels has been stalled.

Nevertheless, the fossil fuel industry's entrenched financial and political influence continues to stymie political will and efforts to advance a science-based transition off fossil fuels grounded in equity. Government failures to act defy the will of US voters, the majority of whom support reducing fossil fuel use, ramping up renewable energy use, and transitioning the US economy from fossil fuels to 100% clean energy, which is seen as the best way to create good jobs [45]. A majority of US voters believe that fossil fuel companies have too much power in the US political system and support making fossil fuel companies pay for the damages they have caused [46, 47]. As action to hold fossil fuel polluters accountable for their economic, climate and health harms becomes increasingly popular, fossil fuel companies are escalating their tactics to greenwash, spread misinformation, and buy out would-be regulators with vast sums of financial political contributions [48–50].

We synthesize key conclusions from the interdisciplinary body of scientific knowledge on the interlinked problems caused by fossil fuels, and we present available solutions for transitioning to clean, equitable alternatives. We focus on five core categories of socio-economic and environmental harms of fossil fuels: (1) the climate crisis, which is driven primarily by fossil fuel emissions; (2) public health harms, (3) environmental injustice, and (4) biodiversity loss driven by fossil-fueled climate change, pollution, and environmental degradation; and (5) petrochemical pollution, with a focus on plastics and agrochemicals. Petrochemicals are the primary non-energy end-product of fossil fuels and their rapidly growing production is an often-overlooked cause of fossil fuel expansion. We then discuss fossil fuel industry disinformation which has been, and remains, a key driver of perpetuating fossil fuels.

We focus on the United States as the world's largest oil and gas producer and dominant contributor to the fossil fuel problem to highlight the role the USA must play as a global leader in advancing a rapid fossil fuel phaseout and just transition to a renewable energy economy. This paper is part of the "Scientists' Warning" series which focuses on specific environmental threats to humanity [51].

Climate crisis

Climate crisis: problem

Fossil fuels are unequivocally driving the global climate crisis. Scientific assessments have repeatedly demonstrated that governments must rapidly phase out fossil fuel production and use to prevent catastrophic harms [52–54]. The production and combustion of oil, gas, and coal are responsible for nearly 90% of human-caused carbon dioxide (CO_2) emissions and approximately 79% of total greenhouse gas emissions [53, 55]. Fossil fuel emissions are rapidly heating the climate, acidifying oceans, and fueling unprecedented climate disasters—intensifying hurricanes, heat waves, droughts, flooding, and extreme fire weather, among other climate-related extremes [5, 53]. The climate emergency is causing premature deaths estimated in the millions [56, 57], endangering public health, imperiling ecosystems, costing trillions in economic damages [58, 59], causing mass displacement and migration, threatening economic, food, and energy security, and increasing overall suffering in the United States and around the world, with harms falling disproportionately on low-income communities and communities of color [53, 54]. Every increase in fossil fuel pollution pushes the world further into the "era of global boiling" [60] and toward dangerous tipping points [61, 62] threatening "human well-being and planetary health" [63]. In 2024, the hottest year in recorded human history [64], the USA suffered 27 major weather and climate disasters, killing at least 568 people and causing damages totaling at least $183 billion [65].

In 2015, world governments met in Paris and agreed to the pivotal goal of limiting global temperature rise to 1.5°C, given the evidence that 2°C heating would lead to catastrophic climate outcomes [66]. As assessed by the IPCC, all pathways consistent with the 1.5°C target require transformational action to rapidly phase out fossil fuels so that global fossil CO_2 emissions peak by 2025—the year we are publishing this warning—and decline by

half by 2030 [53, 66]. Failures in political will to implement necessary climate action have made the 1.5°C benchmark nearly impossible to achieve without overshoot [67]. Because every fraction of a degree matters in avoiding devastating harms, limiting heating as close to 1.5°C as possible—and minimizing the amount and duration of overshoot—is crucial.

International organizations and scientific assessments (e.g. IPCC, International Energy Agency [IEA], United Nations [UN]) have established that, to meet the 1.5°C benchmark, governments must immediately stop approving new fossil fuel extraction and infrastructure projects and phase out existing fossil fuel development [36, 53, 68–75]. Fossil fuel extraction and infrastructure projects already in operation and under development would release enough greenhouse gases to heat the planet well past 1.5°C [53, 73]. Simply stated, the global carbon budget has no room for fossil fuel expansion—meaning no new oil and gas fields, coal mines, pipelines, fossil fuel export terminals, fossil fuel power plants, or other infrastructure. Moreover, existing extraction and infrastructure projects must be phased out to limit the harms from global heating [69, 73].

Upon the release of the IPCC's Sixth Assessment Report in 2021, U.N. Secretary-General Guterres stated, "This report must sound a death knell for coal and fossil fuels, before they destroy our planet.... There must be no new coal plants built after 2021.... Countries should also end all new fossil fuel exploration and production" [76]. In 2021 the Executive Director of the IEA similarly warned, "If governments are serious about the climate crisis, there can be no new investments in oil, gas and coal, from now—from this year" [77].

Yet fossil fuel companies and governments have continued fossil fuel expansion, with plans to extract more than twice as much fossil fuel in 2030 than is consistent with the 1.5°C limit [24]. Leading this expansion, the USA has produced more crude oil than any nation in history each year for the past six years [78] and produces more fossil methane gas than any other country [24], driven largely by the proliferation of fracking in the Permian Basin in Texas and New Mexico [79]. The USA is the world's largest exporter of petroleum products [80] and fossil gas [81], with the largest planned expansion of oil and gas extraction [24, 82], fueling the climate crisis at home and abroad. The USA has made small, but insufficient, reductions in fossil fuel emissions, remaining far behind the cuts to fossil fuel production and use needed to meet national and international climate targets [83, 84]. Even without counting the emissions from US fossil fuel exports, the USA remains the world's largest historical emitter of fossil CO_2, second highest annual CO_2 emitter [25, 85], and the highest methane emitter from oil and gas operations [86].

Given the tight grip and financial hold of the fossil fuel industry on US politics, federal support for fossil fuel expansion spans both major political parties. Upon taking office in January 2025, the second Trump administration directed federal agencies to aggressively expand fossil fuel production, pursue de-regulation of the fossil fuel industry, and rollback climate policy, while continuing to deny the reality of climate change and withdrawing the USA from the Paris Agreement [87–90]. The Biden administration, in contrast, had embraced the scientific reality of climate change as a crisis driven by fossil fuels, re-entered the Paris Agreement, and pursued some regulation of the fossil fuel industry [91–93]. However, its climate and energy policy focused on expanding renewables, most notably through the Inflation Reduction Act, while simultaneously approving many massive new fossil fuel extraction and infrastructure projects as part of an "all-of-the-above" energy strategy (e.g. Willow oil development project in Alaska, Mountain Valley pipeline in Appalachia, LNG and oil export terminals in Gulf Coast communities, record-high approvals of oil and gas drilling permits on public lands) [94, 95]. Although Democrats have periodically responded to enormous grassroots pressure in opposition to specific fossil fuel projects (e.g. Keystone XL pipeline), these have been exceptions. The result at the federal level has been an unstable and inconsistent climate and energy policy, with flip-flopping between administrations on climate rhetoric and policy signaling, and persistent support for US oil and gas expansion. While counter-acting market forces may limit the degree to which any political administration can continue to expand fossil fuel production and infrastructure in the short term [96, 97], momentum in the USA for a clean energy transition is challenged by the extreme politicization of fossil fuels.

Nonetheless momentum for fossil fuel phaseout is growing around the world. Largely in response to calls from civil society and nations in the Global South, world leaders for the first time agreed on the need to "transition away from fossil fuels" at the global climate conference COP28 in December 2023, eight years after the Paris Agreement [98]. The agreement enshrined a commitment to triple renewable energy and double energy efficiency by 2030. This historic climate agreement should signal the beginning of the end of the fossil fuel era. But history shows that commitments on paper are not enough—they must be backed by concrete actions.

Climate crisis: solutions

In the USA, powerful policy levers are available to governments and civil society at the local, state, national, and international levels to phase out fossil fuels and transition to a clean, renewable energy economy. These levers include regulation (e.g. applying and enforcing existing laws), legislation (e.g. polluters pay laws, fossil fuel subsidy reform, land use laws limiting drilling), and litigation (e.g. holding fossil fuel companies accountable, defending existing law). At the same time, building political power across the widest possible cross-section of people suffering acute social, economic, health, environmental, and climate harms by the fossil fuel industry is essential for pushing governments to adopt policies that restrict the expansive and entrenched financial and political influence of the oil, gas, coal, and petrochemical industries. Critically, the USA must reduce both fossil fuel supply and demand to effectively reduce emissions, meet climate targets, and allow for full fossil fuel phaseout [26, 27, 29–31]. Equity requires that the USA lead the way as the world's wealthiest nation and the top oil and gas producer and expander with the means to model a just transition [35, 99, 100]. Studies mapping equitable fossil fuel phaseouts find that the USA should end fossil fuel production by 2034 for a 50% chance of limiting temperature rise to 1.5°C, and by 2031 for a 66% chance, while providing significant financial and technical support to countries in the Global South for the just transition [36, 37].

At the US federal level, while Congress could (and should) pass supply side legislation limiting fossil fuel production, the often partisan and dysfunctional nature of policymaking in Washington, D.C. requires focused attention on existing laws and executive powers. Existing laws, which already provide extensive authority to the executive branch to implement fossil fuel phaseout policies, can be used to great effect [29, 101, 102] by an administration committed to protecting communities and the climate, provided executive action withstands court challenges. For example, federal laws such as the Natural Gas Act [103] and the Deepwater Port Act [104] require agencies to analyze whether

certain projects are in the public or national interest, and the National Environmental Policy Act [105] requires agencies to evaluate projects' effects on the environment and potential mitigation measures. By adopting a more robust climate-and justice-focused review of new applications, the federal government can stop permitting new fossil fuel infrastructure projects, such as pipelines and export terminals, because these projects damage the climate and are not in the public or national interest [101]. Under current federal laws governing leasing of lands and waters, the administration can also withdraw areas from offshore leasing for oil and gas drilling [106] and phase out existing oil and gas production on public lands and waters [107, 108]. Further, the president can declare a national climate emergency under the National Emergencies Act to reinstate the crude oil export ban [109], previously in place from 1975 to 2015, and restrict both private and public investment in international fossil fuel projects [110]. The federal government should also eliminate domestic fossil fuel subsidies, which currently amount to a staggering $757 billion per year (~$2200 per person in the USA) [111]. While federal administrations can recommend ending these subsidies, Congress must act, which it has so far refused to do.

On the demand side, Congress showed, by passing the Inflation Reduction Act and Infrastructure Investment and Jobs Act under the Biden administration, that it can incentivize renewable energy when so motivated. However, Congress can and should go further to replace fossil fuel subsidies with support for clean and renewable energy. In the meantime, if it chooses to exercise it, the US executive branch has extensive power to speed an equitable transition to clean, fossil-free energy [112]. Most US communities must buy electricity from a monopoly corporate utility that uses fossil fuels that pollute communities, obstructs clean energy adoption, and inflates power bills—with low-income households and communities of color disproportionately harmed [113, 114]. To reduce reliance on fossil utility corporations, the administration can prioritize the buildout of distributed clean energy, such as community and rooftop solar, storage and microgrids; energy efficiency; and electric technologies like heat pumps and induction stoves. These solutions are affordable, empower communities to locally produce and store solar and wind energy to withstand climate disasters and utility blackouts, and boost local economies [115–122].

Federal agencies can also issue strong fuel efficiency and greenhouse gas emissions standards for vehicles, using technology which is already developed and ready to rapidly deploy, and redirect funding toward increased support for and equitable access to electric cars and trucks, charging stations, electric public transit, and micro-transit [123]. Transportation is the nation's largest source of fossil fuel pollution, producing about one-third of the nation's greenhouse gas emissions [124]. A rapid transition to zero-emission transportation would significantly reduce fossil fuel emissions and save tens of billions of dollars in health costs and thousands of lives annually [125, 126].

Federal agencies should also adopt and more vigorously enforce regulations governing power plants and refineries. While the Environmental Protection Agency (EPA) has approved new rules in these areas [127], more is needed. For example, the EPA excluded existing fossil gas power plants from new regulations to reduce pollution [128], even though they are quickly becoming the largest source of carbon pollution in the energy sector [129]. This piecemeal approach to regulating emissions from specific sources is likely not enough. Conservation groups, states and tribes have urged EPA to develop comprehensive standards for greenhouse gas emissions under the National Ambient Air Quality Standards (NAAQS) program, a central and as yet underutilized source of power under the Clean Air Act for addressing climate pollution [130, 131].

Policies and pressure to phase out fossil fuels and transition to a clean, renewable energy economy at the local, state, and international levels are also critical, particularly during periods of federal government inaction or hostility to climate action. Efforts have been proliferating at multiple levels of government and civil society using approaches such as legislation, government agency action, litigation, and divestment, catalyzed by pressure from climate justice and environmental justice movements [31, 132].

At the state and local level, supply side actions that have been implemented include fracking bans, ordinances to phase out drilling, and health and safety buffers between drilling sites and communities [133]. Supply side and just transition policies are particularly important in fossil fuel producing states like New Mexico and Texas where oil and gas extraction is intensifying in the Permian Basin, considered the world's largest "carbon bomb" [134]. On the demand side, state and local actions include setting strong greenhouse gas reduction targets; electricity sector and energy efficiency polices such as clean energy standards, net metering, and standards for building construction, clean heat, and appliance efficiency; and transportation sector policies such as incentives for electric vehicles, development of EV charging structure, and vehicle miles traveled (VMT) reduction [135, 136]. There are also state level just transition programs and policies, and efforts to hold state governments accountable for climate policies that violate state constitutional rights to a clean and healthful environment [137].

Grassroots social movements have proved essential for pushing state and local governments to adopt these policies, and to demand action on an international level. These efforts include, among others, direct action (e.g. sit-ins targeting decision-makers or blockading fossil fuel project construction), civil society pressure to include fossil fuel phaseout in climate targets [138], efforts for a fossil fuel non-proliferation treaty [139], and the fossil fuel divestment movement pressuring banks (the primary source of financing for fossil fuel companies) and other investors to stop financing the fossil fuel industry [140, 141].

Last-ditch efforts to prolong the fossil fuel industry are proliferating. These include counter-productive false solutions, like carbon capture and storage (CCS), which would perpetuate fossil fuel use while capturing only some of the resulting emissions, and hydrogen made from fossil fuels. These approaches are ineffective, showing little if any decrease in carbon emissions and adding a significant energy penalty; unsafe, producing harmful air pollutants at each stage in addition to risks from ruptured pipelines; expensive, including the direct costs and the opportunity costs for failing to invest in clean, renewable energy; and unjust, perpetuating the environmental harms of fossil fuels on environmentally overburdened communities [142–147]. Only the rapid phaseout of fossil fuels and a just transition to affordable, clean, renewable energy will enable us to avoid the worst damages of the climate crisis.

Public health crisis

Public health crisis: problem

Health harms from fossil fuels arise directly from pollution generated during production and use [148–150] and indirectly from the impacts of climate change [56]. Global pollution from fossil fuel production and use is a major driver in the burden of disease. Air pollution from fossil fuel combustion accounts for 8.7 million

(equaling 1 in 5) premature deaths per year worldwide and 350 000 premature deaths per year in the USA [151]. In a single year, air pollution from oil and gas production in the USA resulted in 410 000 asthma exacerbations, 2200 new cases of childhood asthma, and 7500 premature deaths in 2016 [152]. US health costs from fossil fuel-generated air pollution alone are estimated to total $820 billion (~$2400 per person in the USA) each year [153]. Although there has long been anecdotal evidence that fossil fuels harm health [154, 155], there has been an influx of new research documenting just how pervasively fossil fuels impact human health.

People who live near places where fossil fuels are extracted are exposed to air pollutants, contaminated water, and excessive light and noise [150, 156–158]. In the USA, 17.6 million people live within one mile of active oil and gas wells [159]. Residing near oil and gas wells is associated with higher risk of adverse health outcomes for people of all ages, including preterm birth [160–162], impaired fetal growth [163], childhood asthma [164, 165], mental health disorders [166, 167], gestational hypertension [168], migraine headaches [169], and death [170]. Compressor stations along pipelines have been associated with elevated concentrations of benzene, a known carcinogen [171].

Fossil fuel waste and abandoned infrastructure also affect human health. People living near coal ash disposal sites, to which approximately 140 million tons are deposited annually in the USA [172], are exposed to particulate matter and heavy metals [156]. An estimated 9 million California residents live near plugged and abandoned oil and gas wells [173], which emit carcinogenic air pollutants and methane [174–176]. Fossil fuel use also presents hazards for the broader US population who encounter this pollution in their daily lives. Exposure to traffic-related air pollution is associated with higher risk of respiratory and cardiovascular disease, adverse birth outcomes, and mortality [177, 178]. Fossil fuel power plants are major emitters of air pollution, and closing these facilities yields improvements in birth outcomes [179], fewer asthma exacerbations [180], and reduced mortality [181]. Petrochemicals, an expanding component of the fossil fuel industry, are increasingly used in households and industrial settings, exposing US residents to endocrine-disrupting chemicals as well as numerous compounds with unknown toxicity [150]. Occupants of homes with fossil gas are exposed to benzene and other carcinogenic compounds entrained in fossil gas (e.g. toluene, heptane) [182–184]. Indoor exposure to NO_2 from gas stove use is likely responsible for ~50 000 current pediatric asthma cases in the USA [185].

Health outcomes related to fossil fuel pollution are worse for racially marginalized communities [162, 163, 186, 187]. Fossil fuel infrastructure is often sited in marginalized communities, frequently as a legacy of historical practices such as redlining [188, 189]. Marginalized communities often face high concentrations of pollution, which is associated with public health harm in these communities [190]. Further work can identify the communities that have been hit the hardest by fossil fuel infrastructure and petrochemicals, which consequently suffer the worst health impacts, and should therefore be prioritized for rapid fossil fuel infrastructure retirement and mitigation to achieve the greatest public health and equity co-benefits.

Fossil fuels also jeopardize public health by driving the climate crisis, considered to be "the greatest global health threat facing the world in the 21st century" [191] and a "public health crisis" [192] by experts. Climate change is increasing incidence of physical and mental health impacts and mortality through multiple pathways: worsening extreme events including heat waves, severe storms, floods, droughts, and wildfires; shifting ranges of disease vectors; threats to food security; and displacement and forced migration, which restrict access to healthcare and other basic services [56, 193, 194]. These harms, though broadly felt, also disproportionately impact marginalized communities which are already disproportionately burdened by other socioenvironmental hazards, as well as susceptible populations including young children, people with certain disabilities, people experiencing homelessness, pregnant people, people with chronic diseases, and older adults [194].

Public health crisis: solutions

The most effective intervention to mitigate health hazards for people living near fossil fuel extraction sites, such as oil and gas wells, would be to reduce or completely eliminate these operations, followed by creating a buffer zone between polluting infrastructure and homes, schools, medical facilities, and other places where people live, work, and play [157]. Asking individuals and families to filter out pollutants at the personal or household levels is not a viable long-term solution at the societal level, given the myriad pollutants produced by oil and gas development, including particulates and gases [157]. To prevent harm from petrochemicals, researchers have called for more stringent testing, transparent accounting of where chemicals are used, and bans on use of toxic petrochemicals in food systems [150].

Many US jurisdictions have already acted, often spurred by research and advocacy from affected communities, and there are opportunities to reduce future risks [195]. In 2022 for example, after years of organizing led by affected residents and their advocates, California Governor Gavin Newsom signed SB 1137 into law, requiring 3200-foot buffer zones between new drilling and sensitive receptors [196]. Even in places where fossil fuel infrastructure has been phased out, it will also be necessary to monitor legacy infrastructure, such as abandoned oil and gas wells, for ongoing pollution [174]. At the state and federal level, there is momentum to increase requirements for the fossil fuel industry to plug and clean up idled oil and gas wells and other infrastructure. Communities and policymakers can also proactively address expected climate-related threats to fossil fuel infrastructure, such as sea level rise and wildfires, by prioritizing retirements of climate-threatened infrastructure [197, 198].

Prioritizing the mitigation of fossil fuel-related hazards in persistently marginalized communities can result in triple co-benefits for climate, health, and equity. For example, the retirement of eight fossil fuel power plants in California resulted in reduced incidence of preterm births among nearby residents, with the greatest reductions in preterm births to Black and Asian people [179]. Similarly, reductions in traffic-related air pollutants improved pregnancy outcomes for people living in Oakland, California, again with the greatest benefits for Black people [199].

The body of evidence to date is clear and consistent: fossil fuel production and use harm public health. Researchers have meticulously documented public health harms associated with fossil fuel production, use, and the consequent climate crisis, which have disproportionate impacts for persistently marginalized populations across the USA and globally. A rapid phaseout of fossil fuels has the potential to produce triple co-benefits and advance climate, health, and equity goals.

Environmental injustice

Environmental injustice: problem

Decades of environmental justice (EJ) research reveal systematic patterns of racial, ethnic, and socioeconomic disparities associated with the location of and human exposures to fossil fuel and climate change-related hazards in the USA [149, 200–204]. The vast majority of EJ studies find that environmental burdens disproportionately impact people of color and low-income populations. Since EJ research began in the 1980s, there has been much debate about whether findings of racial disparities are the result of people of color being disproportionately low-income. This question led EJ researchers to use multivariate statistical analyses to examine the independent associations of racial/ethnic factors and socioeconomic factors with the location of environmental hazards. For example, the seminal 1987 report *Toxic Wastes and Race in the United States*, found both race and poverty to be independent predictors of the locations of hazardous waste facilities and uncontrolled hazardous waste sites [205]. However, the study, along with related replication studies, found race to be a stronger and more consistent independent predictor than indicators of socioeconomic status [202, 206–209]. Systematic reviews of EJ research have found that to be the case across a large body of EJ research, lending support for various racial explanations involving individual, institutional, and systemic discrimination [202, 210–213].

For example, historic redlining—the practice of prohibiting home loans and discouraging investment in predominantly Black or other racially marginalized neighborhoods—along with other types of housing discrimination and racial discrimination in employment and transportation—have contributed significantly to widening wealth gaps, concentrated poverty, and persistent residential segregation [202, 210, 211, 214, 215]. These developments have taken place since the 1960s, coupled with lack of infrastructure development, discriminatory land use practices, and industry siting and government permitting decisions, and have created environmental "sacrifice zones" where environmental burdens fall heaviest on Black, Brown, Indigenous, and poor people, including working class Whites. Polluting industries tend to target new facility sitings in these environmentally overburdened communities, which typically lack political power. These so-called fenceline communities tend to be excluded from environmental decision making, receive few economic benefits of industrial activity, and are places where environmental enforcement is often lacking [211, 214–218].

In the South, the legacies of Jim Crow policies have contributed to the development of oil, gas, and petrochemical industries that disproportionately impact people of color and low-income communities [219, 220]. Louisiana and Texas have the 10 largest petrochemical complexes in North America [221]. Vast chemical-industrial corridors, including the 85-mile Chemical Corridor also known as "Cancer Alley," extend from Louisiana to Port Arthur, Texas, and the area from the Houston Ship Channel to Freeport and Corpus Christi, Texas. This region is home to predominantly Black, Hispanic, and Indigenous communities living on the fence lines of industrial complexes. They experience adverse health impacts, quality of life impacts, displacement, and depressed property values from decades of industrial development [222, 223].

These types of injustices constitute what has been referred to as fossil fuel racism and result from many factors, including lasting legacies of environmental racism and systemic discrimination [201, 202, 210, 224]. By fossil fuel racism, we mean environmental racism, associated with the fossil fuel industry, historic and present-day. Environmental racism refers to racial discrimination in environmental decision making. It can be intentional discrimination due to racial animus or bias, or it can be a pattern of racially disparate outcomes of decision making, though conclusive proof of the former is rarely demonstrable [202, 225–227].

Fossil fuel racism results in the concentration of the externalities of fossil fuel use and development in people of color communities. Air pollution from US oil and gas production is responsible for an estimated $77 billion in health impacts every year. Among states in the USA, Texas, which is comprised of over 60% of people of color, has the highest proportion of associated health damages [152]. Health and welfare risks from oil refineries represent a longstanding EJ issue [228, 229]. Many refineries in communities of color have persistent permit violations and accidents and resist pressure to upgrade pollution controls [230, 231]. Of the 13 refineries that violate EPA's benzene emission standard, 57% of those living nearby are people of color and 43% are living below the poverty line [232]. As a result, affected communities have advocated for better pollution monitoring, closing regulatory loopholes, and strengthening environmental enforcement [233–235].

Similar problems with hazardous air pollutants and risks of natural hazards causing technological failures exist with liquefied natural gas (LNG) export facilities, which are concentrated in communities of color in Louisiana and Texas [236]. As climate-change-induced sea level rise and extreme weather events increase, risks of chemical releases caused by hurricanes and flooding have become an increasing concern in coastal and near-coast EJ communities where industrial pollution is concentrated [204, 237, 238]. Moreover, climate change itself, particularly sea level rise and Arctic sea ice loss, is forcing entire Indigenous communizes in Louisiana and Alaska to relocate [239]. Although climate change impacts coastal communities across the USA, communities vary in their social vulnerability and adaptive capacity, for example, in resources to harden infrastructure and rebuild after coastal flooding [240, 241].

In recent years, fracking has led to the rapid expansion of oil and gas exports [224]. Impacts of fracking include land conversion, water contamination, air pollution, waste disposal, truck traffic, community conflict, noise, and earthquakes [242–244]. Community right-to-know and other procedural justice concerns exist because companies are often not required to disclose chemicals injected into the ground [245]. Environmental injustices associated with fracking locations have been found across the country, including in Indian Country [246–249]. Historically redlined neighborhoods have nearly twice the density of active and inactive oil and gas wells compared to non-redlined areas [188].

Transport of crude oil by pipeline and train is another EJ issue [250, 251]. Indigenous communities have vigorously protested pipeline projects that threaten water, sacred sites, and spiritual values [252, 253]. Indigenous activists are literally on the climate justice frontline, opposing projects to transport crude oil extracted from Canadian tar sands through a highly carbon-intensive, polluting, and environmentally damaging process [254]. This type of civil society opposition is among the suite of solutions to climate injustice and in the tradition of the grassroots environmental justice movement [213, 225, 226].

Environmental injustices associated with the coal industry include the devastating impacts of mountaintop removal mining in poverty-stricken rural areas of Appalachia, uneven enforcement of surface mining regulations, and workplace hazards to miners [255, 256]. A 2012 NAACP study found that approximately 76% of

people living within three miles of one of the top 12 "dirtiest" coal-fired power plants were people of color, compared to 37% for the nation. These residents had an average per capita income of $14 626, compared to the national average of $21 587 at the time [257]. Hundreds of coal-fired power plants have shuttered in the last 20 years and an additional 83 are expected to close by 2030, though over 200 could remain in operation [258]. There will be a lasting, unjust toxic legacy from coal ash often stored in poorly designed slurry ponds and laden with heavy metals [259, 260].

Impacts of climate-related disasters and extreme weather events fall disproportionately on people of color [261]. Racial disparities in governmental emergency preparedness and response contribute to this problem [219]. Exposure of vulnerable populations to extreme heat is an injustice that is growing with climate change. Formerly redlined urban neighborhoods disproportionately experience urban heat island effects [262, 263]. These are places with lower adaptive capacity, where many low-income people of color cannot afford air conditioning or access cooling centers [264]. These factors contribute to relatively high rates of heat-related illness and deaths among people of color and other vulnerable populations including the elderly, the unhoused, those with mental illness, the imprisoned, and farmworkers [265–268]. The fact that climate change exacerbates existing environmental and social injustices is an insidious feature of fossil fuel racism [240, 241].

Environmental injustice: solutions

Addressing fossil fuel racism requires dismantling systems of racial oppression associated with the life cycle of fossil fuels [224–226]. Doing so can achieve real pollution reductions and address long-standing injustices. Federal and state governments, along with civil society, need to acknowledge and correct past and present fossil fuel racism that are the result of systems of power and privilege that continue to promote the production, processing, distribution, and use of fossil fuels at the expense of communities of color and less affluent communities where residents often lack resources and expertise to resist industrial development and cannot readily move to less polluted places [202, 224, 269]. Environmental policies and programs that prevent the creation of new sacrifice zones and mitigate environmental harms in existing ones must be enacted and enforced. A framework for an equitable and fair phaseout of fossil fuels may require standards for assessing cumulative environmental burdens as well as environmental and climate justice legislation that addresses legacy harms created by the fossil fuel industry [37]. Further research and resources are needed for people and places least adaptable and most vulnerable to climate change.

The Biden administration took steps toward such an agenda with its "whole of government" approach to addressing environmental and climate injustice [270, 271]. This included "targeted enforcement of environmental and public health violations in EJ communities; new offices and personnel with environmental and climate justice mandates; and rules and policies promoting EJ priorities, including Tribal co-stewardship of federal resources; more inclusive federal permitting processes; more protective air and water pollution standards to address risks to frontline communities; and resiliency and energy efficiency upgrades to affordable housing" [272]. The Biden administration's Office of Management and Budget required federal agencies to update what factors to consider and how to conduct benefit-cost analyses in regulatory impact analyses in rulemaking. President Biden created the first-ever White House Environmental Justice Advisory Council. Through his Justice40 Initiative, President Biden directed federal agencies to work with state governments to ensure that 40% of the benefits of climate and clean energy program authorized by the Infrastructure Investment and Jobs Act of 2021 and the Inflation Reduction Act of 2022 be directed to disadvantaged communities as defined by the Community Environmental Justice Screen Tool (CEJST) [91, 273].

As of late 2024, there were over 500 programs across 16 agencies covered by Justice40, including multi-billion-dollar loan and grant programs, workforce training and development, tax incentives, and environmental remediation and pollution control programs. These initiatives have benefitted EJ communities while supporting clean energy transition, for example in funding EV vehicles and battery production, EV charging infrastructure, and solar development [274, 275]. Justice40 and related clean energy efforts are not without distractors and challenges, however [276–278]. For example, dangerous, costly, and counterproductive CCS projects and hydrogen hubs are often being sited in the same communities that have historically borne the environmental, health and economic burdens of fossil fuel industries [143, 279, 280]. Federal agencies must do more to incorporate direct-from-community information, including local and Indigenous knowledges, into permitting decisions [281–283] and seek free, prior, and informed consent of tribal governments, measures that go beyond mere consultation [284].

However, under the second Trump administration, federal environmental justice rollbacks are the order of the day. Upon taking office in January 2025, President Trump rescinded numerous EJ executive orders, including those related to Justice40. He sought to cancel EJ grants, close the EPA Office of Environmental Justice and External Civil Rights, and furloughed federal EJ program employees [285]. The Trump administration took down EJ websites and data tools, including CEJST and EPA's EJ Screening Tool, EJSCREEN, an online mapping tool accessible to the public. Federal agency equity action plans and environmental justice strategic plans are being scuttled as part of President Trump's attacks on diversity, equity, and inclusion and his rescission of President Biden's Executive Order 13895 "Advancing Racial Equity and Support for Underserved Communities Through the Federal Government" and Executive Order 14906 "Revitalizing Our Nation's Commitment to Environmental Justice for All" [286]. Some of these measures could be forestalled by federal court rulings, providing the administration adheres to them [287, 288].

The Trump administration's executive actions will slow federal efforts to mitigate the disproportionate environmental impacts of fossil fuel and petrochemical industries and will interfere with the clean energy transition. Although many states will continue their efforts, more durable policy solutions are needed that are not as susceptible to presidential politics. For example, environmental justice goals and programs could be codified into federal law such as the Donald McEachin Environmental Justice For All Act.

Biodiversity loss and extinction

Biodiversity loss and extinction: problem

Biodiversity is the fabric of life on Earth and the life support system that underpins planetary health and human well-being [289]. Fossil fuels pose an existential threat to the planet's biodiversity. Fossil fuels drive the climate crisis which is accelerating species extinction risk and ecosystem degradation, and cause biodiversity harms through fossil fuel development and

petrochemical pollution. In a destructive cycle, the fossil-fuel-driven degradation of wild places and loss of species worsens the climate crisis by disrupting ecosystem-based carbon dioxide removal from the atmosphere, which is needed to curb global heating [290]. Overall, fossil-fuel-driven biodiversity loss has direct and dire impacts on food security and nutrition, water quality and availability, health and well-being, carbon storage and sequestration, resilience to climate change, and almost all of nature's vital contributions [291], on top of the incalculable, non-monetizable costs of species extinctions.

Worldwide an estimated one million animal and plant species are threatened with extinction, with climate change as a primary driver, alongside habitat destruction and exploitation [292]. Scientists have long documented the widespread and growing stresses of anthropogenic climate change on species and ecosystems, as rising temperatures, more extreme weather events, coastal flooding, sea ice and glacier melt, and other climate hazards make conditions more inhospitable. Climate change is disrupting species' distributions, timing of breeding and migration, physiology, vital rates, and genetics [293–296]. It is spreading disease and invasive species; increasing mortality and localized extinctions; and deteriorating ecosystem processes [297–299]. Climate change-related local extinctions are already widespread [300].

Every increase in fossil fuel pollution and resulting climate stress pushes ecosystems closer to tipping points and amplifies extinction risk. With ~1.5°C temperature rise as of 2024, the world's coral reef ecosystems—which support a quarter of ocean life and the livelihoods of a half billion people—are in crisis due to increasingly frequent and severe bleaching events from ocean heating paired with ocean acidification [301]. Half of the world's reefs have already been lost [302] and near total global reef collapse is projected at 2°C temperature rise [66]. An estimated 1.6% of species are projected to become extinct at the current level of temperature rise [303]. Numerous studies have projected catastrophic species losses with continued fossil fuel pollution with, for example, the climate-related extinction of 14%–32% of animal and plant species—representing the potential loss of 3 million to 6 million species—in the next 50 years, even under intermediate fossil fuel emissions scenarios [304]. Scientists have called for the urgent transformation of our energy system away from fossil fuels to prevent a mass extinction event [305].

Fossil fuel development itself also causes a wide array of harms to species and ecosystems: destroying and fragmenting wildlife habitat, causing air, noise, and light pollution, contaminating surface and ground water and reducing water supplies, and facilitating the spread of ecologically disruptive invasive species [306–308], with similar harms in the marine environment [309]. Fossil fuel infrastructure creates the significant risk of oil spills and brine spills, which can kill wildlife and cause long-term impacts over large areas [310]. The fossil fuel-based energy system has led to mortality, changes in behavior, and population declines in many species, disruptions to community composition, and loss of ecosystem function [311, 312].

Biodiversity loss and extinction: solutions

The solutions to the climate crisis and biodiversity extinction crisis are interlinked and synergistic [292]. Rapidly phasing out fossil fuels to stem the climate crisis is necessary to prevent species extinctions and maintain functioning wildlife populations and ecosystems and the innumerable benefits they provide. In turn, maintaining healthy wildlife populations and intact ecosystems is our strongest natural defense against climate change [313]. Intact terrestrial and marine ecosystems store and sequester enormous amounts of carbon, currently drawing down half of human-caused CO_2 emissions [314]. Healthy wild animal populations enhance the capacity of ecosystems to capture and store carbon via numerous mechanisms, from nutrient redistribution and seed dispersal by native herbivores to the control of grazers by apex predators to ecosystem engineering by beavers [314]. While fossil fuel phaseout is key to stemming the climate crisis, the drawdown of some existing CO_2 from the atmosphere is also necessary to limit temperature rise to 1.5°C, and ecosystem-based CO_2 removal is the most effective and sustainable way to deliver those drawdowns [315]. Intact ecosystems from coral reefs, coastal wetlands, mangroves, to forests also serve as critical natural buffers to extreme weather events and other climate impacts like flooding, storm surge, and heat waves [316].

Building on the Convention on Biological Diversity's Global Biodiversity Framework, the USA should fully conserve and protect at least 30% of its lands and waters by 2030, prioritizing areas that are important for biodiversity, carbon storage and sequestration, and habitat connectivity, while recognizing and respecting the rights of Indigenous Peoples [317]. By 2030, the USA should also ensure that 30% of degraded terrestrial and aquatic ecosystems are under effective restoration that enhances not only carbon storage and sequestration but biodiversity, ecosystem integrity, and connectivity. The USA should halt the extinction of wildlife and plant species on its lands and waters by protecting all imperiled species under its Endangered Species Act, investing in the conservation and recovery of threatened and endangered species to abundant population levels, and supporting both federal and state-level conservation efforts to rebuild wild populations [318]. Because of its disproportionately large role in driving the climate and biodiversity crises [319], the USA must also fund ecosystem and species protection abroad to ensure global climate and biodiversity targets are met.

As the USA transitions from fossil fuels to clean, renewable energy systems, it is critical that the renewable energy build-out protects wildlife and ecosystems [320]. Maximizing distributed energy resources like rooftop and community solar, storage, and microgrids in the built environment will protect ecosystems from development while increasing community energy resilience, avoiding transmission losses and harms, and co-locating energy production with demand [321].

Petrochemical pollution

Petrochemicals are chemicals made from fossil fuel feedstocks using fossil fuel energy sources, and their production and use are a rapidly growing and often overlooked source of fossil fuel expansion. As fossil fuel use declines in the energy and transport sectors, the tightly linked fossil fuel and petrochemical industries are increasing investments in the production of petrochemicals, threatening further fossil fuel lock-in [322, 323]. More than 75% of petrochemicals produced globally are used in the manufacture of plastics and agrochemicals [324], making these industries largely responsible for petrochemical production and its resulting harms.

Plastics

Plastics: problem

Plastic pollution is ubiquitous and one of the most pressing global environmental crises [325, 326]. The plastics and fossil fuel industries are tightly coupled [327]. Virtually all plastics are made from fossil fuel feedstock, and plastic products are the

largest petrochemical end-use product [323, 324, 327, 328]. Currently about 12% of global crude oil demand and 8.5% of fossil gas demand goes to plastics production [329]. Annual global plastics production has quadrupled since the 1970s [330], totaling 460 million tons in 2019 [331], and the interlinked fossil fuel and plastic industries plan to further double or triple plastic production by 2050 [332]. The fossil fuel industry is pivoting to invest in plastics production to make up for losses from traditional fossil fuel demand such as oil for transportation fuels [333]. On the current trajectory, plastics and other petrochemicals are expected to drive half the growth in oil demand by 2050 [334]. The United States is a dominant contributor to the plastic pollution crisis as the world's second largest plastic producer and consumer [335], home to the world's largest planned expansion of plastic production facilities [322], and largest producer of plastic waste on a total and per-capita basis [336].

Plastics production and disposal cause a wide array of harms to the climate, public health, environmental justice, and biodiversity. The health-related harms of plastics production are estimated to cost hundreds of billions of dollars globally each year, as are the social costs from the greenhouse gas pollution emitted by plastics production [337]. There are at least 16 000 plastics chemicals, of which 26% are known to be hazardous to human and environmental health [324, 338]. Plastics break down into nano- and micro-sized plastics (NMPs) that are found in our oceans, drinking water, soil, air, food, and our bodies [339]. Plastic pollution, climate change, and biodiversity loss are threat multipliers [340] and a triple global threat to a safe, clean, healthy, and sustainable environment [341–344].

The full life cycle of plastics, including extraction of feedstocks, production, manufacture, consumption, transport, waste management, unintentional and intentional releases of plastics to the environment, and removal and remediation, produce significant greenhouse gas emissions that worsen the climate crisis [329]. In 2019, global primary plastics production generated approximately 2.24 gigatons of carbon dioxide equivalent ($GtCO_2e$), representing 5.3% of global greenhouse gas emissions [329]. This does not include the emissions from other stages of the plastic lifecycle [63, 343, 345–350]. At expected rates of plastic production, by 2050 the plastics sector will consume up to 26% of the global carbon budget for limiting global heating to 1.5°C [329].

Plastics pose risks to public health with direct and indirect exposures from plastic particles and their associated toxic chemicals, including air, soil, and water pollution all along the plastics life cycle [337, 339, 344]. Plastic pollution disproportionately impacts Indigenous communities, communities of color, and low-income communities including informal waste workers [351], for example, in the US Gulf South and Ohio River Valley where petrochemical and plastics facilities are concentrated, worsening environmental injustice. An estimated 19–23 million metric tons of plastics enter aquatic systems annually, harming marine species through entanglement, ingestion, and associated toxicity, and facilitating invasive species and pathogen spread, with similar threats to terrestrial ecosystems [352–354]. The climate crisis is magnifying these impacts. For example, climate-driven extreme weather events can increase the transboundary movement of plastic pollution, while rising temperatures increase plastic fragmentation and the leaching of toxic chemicals from plastics [355].

Investigative and academic research [356–358] illustrate how the petrochemical and bio-based plastics [359] industries have misled the public about the safety and sustainability of the products they release onto the market including their recyclability and biodegradability. In the USA, 6.2% of plastics were recycled in 2015 [360]. Globally, only 9% of plastics have been recycled, while 12% have been incinerated and 79% have accumulated in landfills or the environment [361]. Despite the Plastic Waste Amendments to the Basel Convention in 2021, a "new global waste economy" has emerged as an illicit trade of plastic waste to developing countries where open burning, waste to energy incineration, and dumping may be the only options to handle growing volumes of bales of contaminated and low value plastics [362, 363]. Municipal plastic waste incineration can significantly increase greenhouse gases [364] and toxic emissions [365].

Plastics: solutions

The safest, most sustainable, effective, economic, just, and equitable responses to plastics pollution prevention are ambitious global and national targets to reduce primary plastic production [366, 367]. One key mechanism is a global legally binding plastics treaty that sets ambitious targets to phase down the production of primary plastics polymers (PPP) (i.e. polymers used for the first time to create plastic products in any form) [323, 368]. Scientific consensus on sustainable PPP reduction targets has not yet been established. However, a previously proposed global reduction target of 2.35% per year over the next 15 years (~28% cumulative reduction) [369] would still lead to cumulative production of 20 000 million metric tons of plastic production by 2040, meaning substantially higher PPP reduction targets are necessary [367–370]. An effective global plastics treaty should also prioritize financial, capacity, and technical support for non-plastic substitutes, systems, and technologies that have been assessed and found safe and sustainable including reuse, refill, repair, repurpose and remanufacture [371]. The science body of the global plastics treaty will need to establish harmonized definitions, criteria, and standards for essentiality (i.e. essential use) [372] and transparency; and mandatory monitoring and reporting to support compliance and enforcement [371]. The science body should adhere to a robust conflict of interest policy and include independent academic representation across multiple disciplines, as well as expert representation from all affected stakeholders and rights holders [373].

Other critical measures to reduce plastics production include phasing out unnecessary or avoidable (non-essential), unsafe, and unsustainable (problematic) plastics; halting buildouts of new plastics production facilities; and removing subsidies and other incentives for avoidable and problematic plastics and associated services and technologies [323, 368, 374]. In an effort to phase out harmful plastics, many countries are turning to "bioplastic" alternatives including bio-based plastics and plastics with biodegradable properties [375]. Bio-based plastics are composed of polymers made entirely or partially from biological materials including plant, animal, and marine biomass, but they are not necessarily biodegradable. Biodegradable plastics are made from bio-based or fossil carbon-based polymers that are intended to biodegrade more rapidly than conventional plastics but require specific conditions. Bioplastics represent only about 0.5% of the over 400 million metric tons of plastics produced annually [376, 377] but global production capacity of bioplastics is forecast to rapidly increase [378]. Many bioplastics contain fossil carbon feedstock and, like conventional plastics, can contain thousands of chemicals of concern [379]. Whether a bioplastic (a bio-based plastic or plastic with biodegradable properties) is a viable plastic alternative depends on many factors including displacement of food crops and fossil fuel-derived pesticides used in plastics biofeedstock production, toxicity, lifecycle emissions and

releases, biodegradability, affordability, accessibility, environmental degradation conditions, and availability of industrial composting facilities [380]. Bioplastics, along with non-plastic substitutes, will need to be assessed based on the same hazard-based safety, sustainability, transparency, and essentiality criteria as conventional fossil carbon-derived plastics to avoid regrettable substitutes including those that contribute to higher climate emissions.

Agrochemicals

Agrochemicals: problem

Agrochemicals, consisting mainly of synthetic chemical fertilizers and pesticides, are widely used in modern-day industrial agriculture. An estimated 99% of synthetic chemicals are derived from fossil fuels [381], with synthetic pesticides and nitrogen-based fertilizers derived mainly from petroleum, fracked gas and coal [324, 382, 383].

Fossil fuel-derived fertilizers and pesticides are some of the most widely dispersed pollutants on the planet. In 2015 alone, the USA used over 26 billion pounds of nitrogen fertilizer [384]. With just over 80 pounds of nitrogen fertilizers used per acre of cropland on average [385], that translates to approximately 322 million acres of land in the USA treated with this fossil fuel product. In 2021, around one billion pounds of pesticides were used in US agriculture in over 1.3 billion acre-treatments, which accounts for the number of US acres treated with pesticides multiplied by the number of applications made to that acreage [386]. The USA is the world's third largest user of nitrogen-based fertilizers [387] and the second largest user of pesticides [388], indicating that it is a significant driver of the demand for fossil fuel-derived fertilizers and pesticides.

On average only about half of fossil fuel-derived nitrogen applied as fertilizer gets taken up by plants [389], with the rest ending up polluting air, soil, or water. Airborne ammonia emissions from fossil fuel-derived fertilizer can lead to formation of acid rain, which can acidify soils and water [390]. Soil contamination from synthetic nitrogen fertilizers reduces native plant biodiversity, abundance, and richness [391, 392]. Fossil fuel-derived nitrogen fertilizer runoff into water bodies can lead to hypoxic "dead zones" that are incompatible with aquatic life [381, 393].

Ecosystems around the world are contaminated with fossil fuel-derived pesticides [394], which are widely recognized as a major cause of biodiversity decline [395–398]. The cascading effects on these ecosystems are significant, with some fossil fuel-derived pesticides found to be putting over a hundred species at risk of extinction just in the USA [399, 400]. Pesticides are also known to have serious harms to human health, with low-income communities and people of color disproportionately bearing the societal burden of pesticide harm [401].

Agrochemicals: solutions

Industrial agriculture—characterized by widespread ecosystem degradation, resource extraction, and lack of crop diversification—has become dependent on fossil fuel-derived chemical inputs to counteract growing practices that are depletive and unsustainable [402]. This dependence on petrochemicals accelerates climate change and further degrades the environment, leading to ecosystems that are less resilient to a changing climate. There is increasing global awareness that agroecology or diversified and more localized organic agriculture are the farming systems we must adopt as a society to increase food security and mitigate agriculture's impact on the global climate crisis and biodiversity decline [292, 403, 404]. As this transition to ending fossil fuel use in agriculture takes place, integrated pest management (IPM) strategies that explicitly call for reducing synthetic pesticide and fertilizer use can start us on the path to sustainability in agriculture.

Fossil fuel industry disinformation

Fossil fuel industry disinformation: problem

The fossil fuel industry has known since the 1950s that its products could cause disruptive climate change, and by the late 1970s the industry knew that in time they almost certainly would. But rather than share this information, the industry has waged a multi-decade, multi-billion-dollar campaign of concealment, disinformation, denial, and delay to prevent climate action and the transition to clean energy.

During the 1950s and '60s, academic scientists explained in scientific papers, popular media, and testimony to governments—and alerted the fossil fuel industry itself—that fossil fuel combustion was increasing the concentration of CO_2 in the atmosphere, which, in time, would likely lead to damaging climate change [3, 405]. As later uncovered by scholars and investigative journalists, during the 1970s and '80s, the fossil fuel industry internally amassed extensive evidence of the potentially major threat fossil fuels posed to the planetary climate, commissioning reports, convening a task force, and conducting original research [406]. ExxonMobil's research program in the 1970s and '80s predicted global warming with high accuracy, and other major companies had a similar understanding of the scientific evidence [406]. Yet, instead of alerting the public about the impending climate crisis and taking action, the industry concealed what it knew [2, 407–414].

By the mid-1990s a scientific consensus had emerged that global warming was underway [415]. The public communication of that consensus began with the pivotal Congressional testimony of US climate scientist Dr James Hansen and the creation of the IPCC in 1988, and the publication of the IPCC's second assessment report in 1995 [416]. As climate change became front page news and political will grew to address it, the fossil fuel industry, its trade associations, and its ideological allies began a massive public relations campaign to undermine public understanding of the problem and block meaningful policy action. Since then, the fossil fuel industry has actively denied and cast doubt on climate science, confused the public and politicians, and prevented climate and clean energy policies through disinformation, lobbying, and propaganda. Mimicking the tobacco industry, a key industry tactic was—and continues to be—overemphasizing uncertainty in the science and falsely claiming there is no consensus among scientific experts and therefore no basis for taking action [2, 415, 417–419].

Other tactics have included denigrating climate models, presenting global cooling as a legitimate alternative interpretation of the scientific data, and feigning ignorance about the discernibility of human-caused warming. Companies also engaged in scaremongering about the economy. A 1995 "communications plan" of the industry's Global Climate Coalition identified their key public "messages" as not just "continued uncertainty of the science" but also "Economics—loss of jobs, higher energy costs, diminished competitiveness" and "Sovereignty—America concedes energy/environmental policy to international bureaucracy" [420]. The industry spread its disinformation directly through misleading advertisements, company reports, inadequate shareholder disclosure, and indirectly by funding and cooperating with contrarian scientists, climate change-denying organizations, and

right-wing politicians [2, 421–424]. Recent investigations have revealed that the fossil fuel industry also long concealed and misled the public and decision-makers about the serious health harms from fossil fuels [425] and the infeasibility of recycling plastics, one of its core products [358, 426].

The industry's disinformation campaign dovetailed with the decades-long effort by corporate America—business leaders, their trade organizations, and thinktanks—to promote an anti-governance, anti-regulation agenda that asserted that climate change (and other matters) should be left to the market to sort out, and that government was not—and could not be—the solution [427]. The reality, as economist Nicolas Stern has aptly noted, is that climate change is a market failure where "those who damage others by emitting greenhouse gases generally do not pay," which requires government action to address [428]. Yet by the mid-1990s, in large part due to the duplicity and disinformation of the fossil fuel industry and allies, many American citizens and political leaders had been persuaded "to trust the market" and eschew regulation on climate change.

In the mid-2000s as the consensus on climate change strengthened, the fossil fuel industry shifted its public affairs strategy from outright public denial of climate change to more subtle, insidious forms of propaganda [414, 419, 429]. Among their key tactics, fossil fuel companies routinely cast climate change as a ''risk'' rather than a reality, even after the scientific community had stated that climate change was "unequivocal" [414]. They use "greenwashing" in advertising to portray companies as environmentally conscious [430] and committed to low-carbon technologies when, in fact, from 2008 to 2022 oil and gas companies never spent more than 1% of their collective annual budgets on low-carbon projects [431]. Many companies have made empty pledges to reach net-zero emissions that their business models cannot achieve [432]. They deploy rhetoric on "individualized responsibility," in which they shift blame for climate change from producers to consumers and their role in sustaining "demand," even though much of this demand could be answered by renewable energy. They promote "fossil fuel solutionism," presenting their industry as an essential and inevitable part of the solution to the climate crisis, in contradiction to the scientific evidence that continued fossil fuel production and use will worsen the climate crisis. And they use "technological shell games" in which they downplay the climate harms from fossil fuels, for example by falsely marketing methane as "clean," and promote ineffective, expensive fossil fuel technologies such as CCS [433]. As the cost of solar and wind energy continues to drop, the fossil fuel industry is falsely casting clean, renewable alternatives to fossil fuels as unreliable and inviable [434]. Alongside these propaganda tactics, climate disinformation remains rife on social media, much of it apparently emanating from sources connected to the fossil fuel industry [435].

These tactics continue to be pervasive and highly influential. The IPCC in 2022 concluded that misinformation and politicization of climate-change science in the USA by vested interests "has sowed uncertainty and impeded recognition of risk" and "limited climate action" [436]. Polls consistently show that many Americans—and significant portions of populations in other countries as well—continue to doubt the reality or significance of climate change [437–439]. As of 2024, 29% of Americans ascribed the observed warming to "natural changes in the environment," rather than to human activities, while 22% of Americans still think there is "a lot of disagreement" among scientists as to whether global warming is happening [440]. And the World Economic Forum has concluded that disinformation is now one of the leading global risks [441].

Fossil fuel industry disinformation: solutions

As new evidence continues to be uncovered documenting the fossil fuel industry's decades-long deception, efforts have ramped up to expose industry disinformation and hold fossil fuel polluters accountable for their damages and deceit. These efforts have broad public support. A majority of US voters across party lines support making fossil fuel companies pay for their climate damages and support litigation against these companies for their role in deceiving the public [47, 442].

In the case of the tobacco industry, Congressional investigations, litigation, and industry whistleblowers were critical in exposing documents that led to successful lawsuits and tobacco control. Continued work by investigative journalists, researchers, activists, and government to reveal climate disinformation is essential, as is communication and public education on the scientific consensus on climate change and the needed fossil fuel phaseout.

Dozens of states, counties, and municipalities across the USA have filed nuisance and fraud lawsuits against major oil and gas corporations for deceiving the public about their central role in the climate crisis [443]. The goal of these activities is to hold industry entities accountable for the damage that their products have caused, or, in the case of consumer fraud cases, the fraud itself. The US Department of Justice and State Attorneys General can and should investigate legal violations by fossil fuel polluters and prosecute them to the maximum extent that the law permits.

States and other entities are exploring means to hold fossil fuel producers and refiners strictly liable for costs arising from their products' emissions [444]. In 2024 Vermont and New York became the first states to enact a "polluter pays" law requiring fossil fuel companies to pay a share of the damages from climate change [445], and similar bills have been introduced in California, Maryland, and Massachusetts, while a federal bill has been introduced in Congress. Advances in attribution science, which can attribute specific climate change damage to individual polluters, provide the scientific foundation for these legislative efforts [446–449]. In addition, the federal government can continue to enforce the Clean Air Act, which recent research shows was intended to cover CO_2 as a pollutant [3].

Conclusion

Fossil fuels and the fossil fuel industry are at the core of interlinked, overlapping crises threatening people, wildlife, and the planet (Fig. 1). Stopping fossil fuel expansion and rapidly phasing out fossil fuel production and use is necessary not only to prevent catastrophic damages from the climate crisis but also to stem the inter-connected public health, environmental justice, biodiversity extinction, and petrochemical pollution crises worsened by fossil fuels.

The fossil-fueled climate crisis is cutting lives short, imperiling ecosystems, costing global economies hundreds of billions of dollars in damages annually, and threatening national security and a livable future. Fossil fuel pollution causes public health harms at all stages of human development—preterm birth, impaired fetal growth, childhood asthma, worse mental health, respiratory and cardiovascular disease, cancer, and even mortality. Fossil fuel combustion is responsible for 1 in 5 premature deaths worldwide and hundreds of thousands of premature deaths in

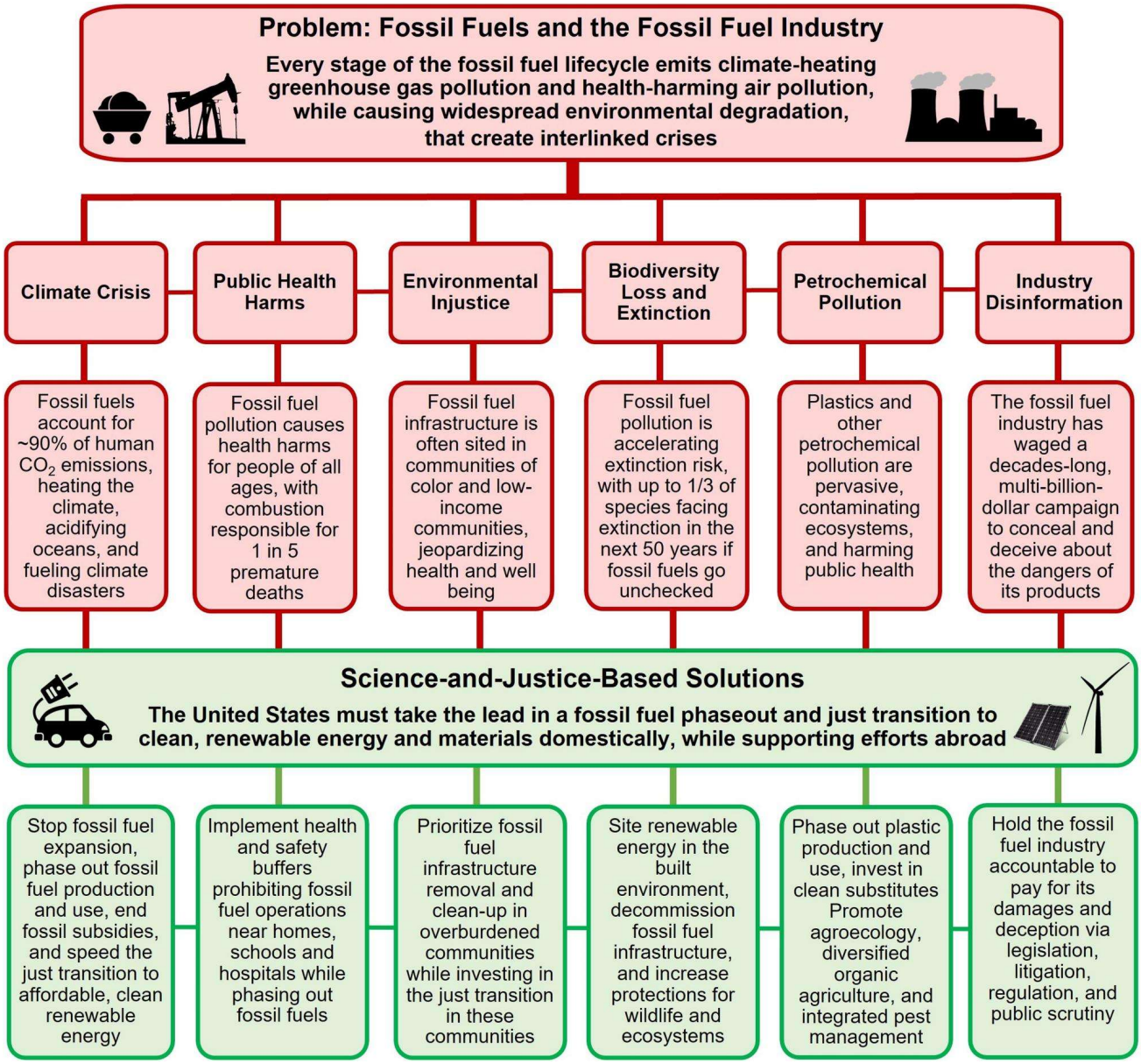


Figure 1. Pervasive harms from fossil fuels and the fossil fuel industry and solutions for a just transition to clean alternatives.

the USA each year. These health risks, as well as quality of life impacts and hazards of industrial accidents, disproportionately burden people of color and low-income communities. Fossil fuel pollution is accelerating extinction risk, with up to one-third of wildlife species facing extinction in the next 50 years if fossil fuel pollution continues unchecked. Fossil fuel-derived plastic pollution is choking our oceans, and microplastics are found in our food, drinking water, air, and even our bodies. Fossil fuel-derived fertilizers and pesticides contaminate ecosystems, reduce biodiversity, and harm public health.

In the face of this evidence, the fossil fuel industry and enablers have waged a successful, decades-long, multi-billion-dollar disinformation campaign to deceive the public and governments about the dangers of its products and block the necessary fossil fuel phaseout. The industry has concealed and denied established science, shifted blame onto consumers, and peddled false solutions like CCS and fossil hydrogen while falsely casting alternatives to fossil fuels as inviable. Government delay in phasing out fossil fuels has been costly in monetary and non-monetary terms. While the enormous damages attributable to the fossil fuel industry are difficult to fully quantify, estimates of the damages caused by the "carbon majors"—the biggest-emitting fossil fuel companies—range into many trillions of dollars [58, 59]. In the USA alone, damages from fossil fuels are estimated at hundreds of billions of dollars each year, factoring in loss of life, soaring health costs, emissions-intensified climate disasters, diminished ecosystem services, and climate adaptation costs, among other harms, all of which increase the cost of living, reduce quality of life, and cause escalating hardship for everyday Americans [54, 65, 153].

Action to speed the transition from fossil fuels to clean, renewable energy could not be more urgent. Fortunately, equitable, affordable, clean alternatives already exist across sectors which can replace fossil fuels while protecting people and the planet. As a wealthy nation with high capacity, the USA already has the necessary technology and policy levers to transition to a clean, renewable energy economy where people and wildlife thrive. The key barrier is the lack of political will which has been stymied by

the entrenched political and financial influence of the fossil fuel industry. Grassroots social movements are essential to push governments to implement fossil fuel phaseout and just transition policies that protect the public interest, limit the influence of the fossil fuel industry, and hold fossil fuel polluters accountable for their damages and deception.

In the United States, the government can and must fully phase out fossil fuel production and use by rapidly ratcheting down both supply and demand, while safely and equitably retiring dirty energy infrastructure, whereby workers receive community benefits and impacted communities receive redevelopment supports [450]. Under existing law, the federal government is empowered to phase out fossil fuel supply by halting new production and phasing out existing production on public lands and waters, stopping new fossil fuel infrastructure projects, declaring a national climate emergency, ending fossil fuel exports, and eliminating federal fossil fuel subsidies. The federal government is likewise empowered to speed the just transition by putting in place protections for impacted workers and communities and prioritizing the build-out of renewable solar and wind energy and storage, energy efficiency improvements, and electric technologies in the power sector, and battery electric vehicles and charging infrastructure in the transportation sector.

The government can maximize public health and environmental justice benefits of the energy transition by prioritizing the decommissioning and clean-up of aging fossil fuel infrastructure in overburdened communities. The government can likewise prioritize investments in renewable energy in cumulatively burdened communities to ensure equitable access to clean, affordable energy, promote economic development, and increase community resilience.

The just transition off fossil fuels can provide immediate benefits for biodiversity through the decommissioning of polluting infrastructure, siting of renewable energy infrastructure in the existing built environment and degraded lands, and protecting and restoring healthy wildlife populations and habitats, which provide essential benefits including massive carbon storage and sequestration. Meanwhile, setting ambitious global and national plastics production reduction targets will promote sustainable materials manufacture. Reducing our dependence on fossil fuel-derived fertilizers and pesticides using agroecology, diversified organic agriculture, and integrated pest management can increase food security and lessen agriculture's impact on biodiversity and the global climate.

Action to transition from fossil fuels to clean, renewable energy and materials must occur across sectors to prevent industry "escape hatches." This includes false solutions such as CCS and fossil fuel hydrogen which throw a lifeline to the fossil fuel industry. As fossil fuel use declines in the US energy and transportation sectors, the fossil fuel industry has responded by increasing investment in plastics and petrochemical production, and ramping up fossil fuel exports, to continue fossil fuel extraction and use. Preventing fossil fuel industry "escape hatches" is necessary to avoid perpetuating fossil fuel harms and achieve the transition to a clean, renewable energy economy.

Holding the fossil fuel industry accountable for its deception and insisting that the industry pay for the damage it has caused is both a straightforward matter of accountability and can help to cover the costs of a just transition. Examples include legislative efforts to hold major fossil fuel companies liable for costs arising from their products' emissions and to require the oil and gas industry to plug and clean up abandoned wells. Independent scientists [451] and advocates must continue to expose fossil fuel industry disinformation, push for transparency, and communicate the need for urgent action.

Equity requires that the fossil fuel phaseout not be the burden of those least responsible. The USA has a disproportionately large role in driving fossil fuel production and use, and the resulting harms. The USA must lead the fossil fuel phaseout and the just transition domestically while supporting these efforts abroad through significant funding, knowledge transfer, and capacity building.

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Supplementary data

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